Solutions for CO2-free Powertrains

- DEUTZ H2 Hydrogen Engine

MDEC 2023

Agenda

- Dual strategy for a Sustainable Drive System Portfolio
- Introduction to DEUTZ H2 Internal Combustion Engine (ICE)
- Emissions Characteristics of the TCG7.8H2
- Summary

Tackling the challenges in off-highway applications

Open-minded approach to technology

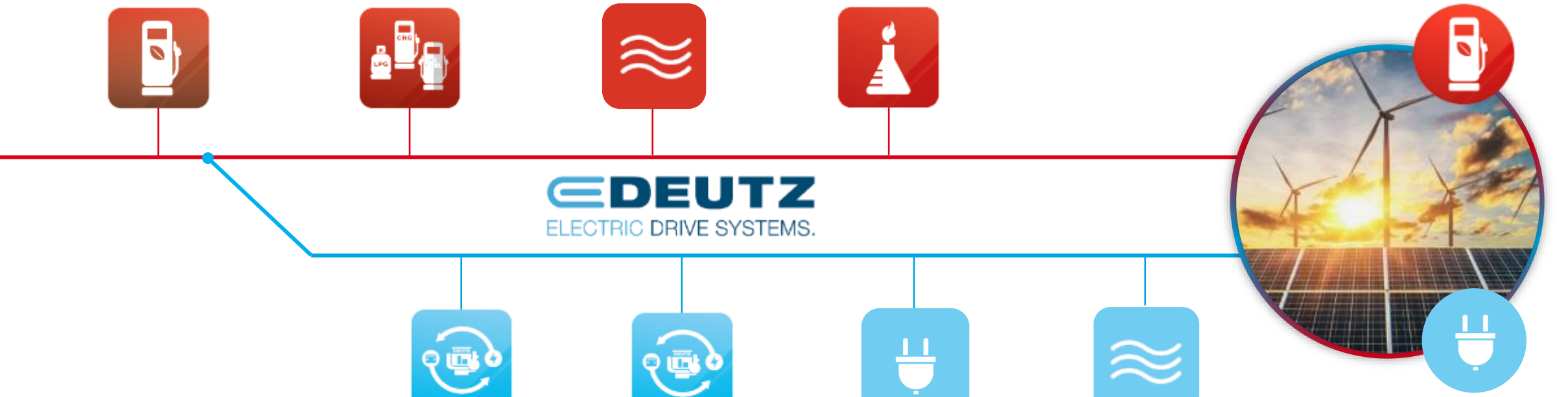
Biodiesel

Multi-fuel

Hydrogen

Synthetic fuels

Sustainable fuels



48V systems

360V systems

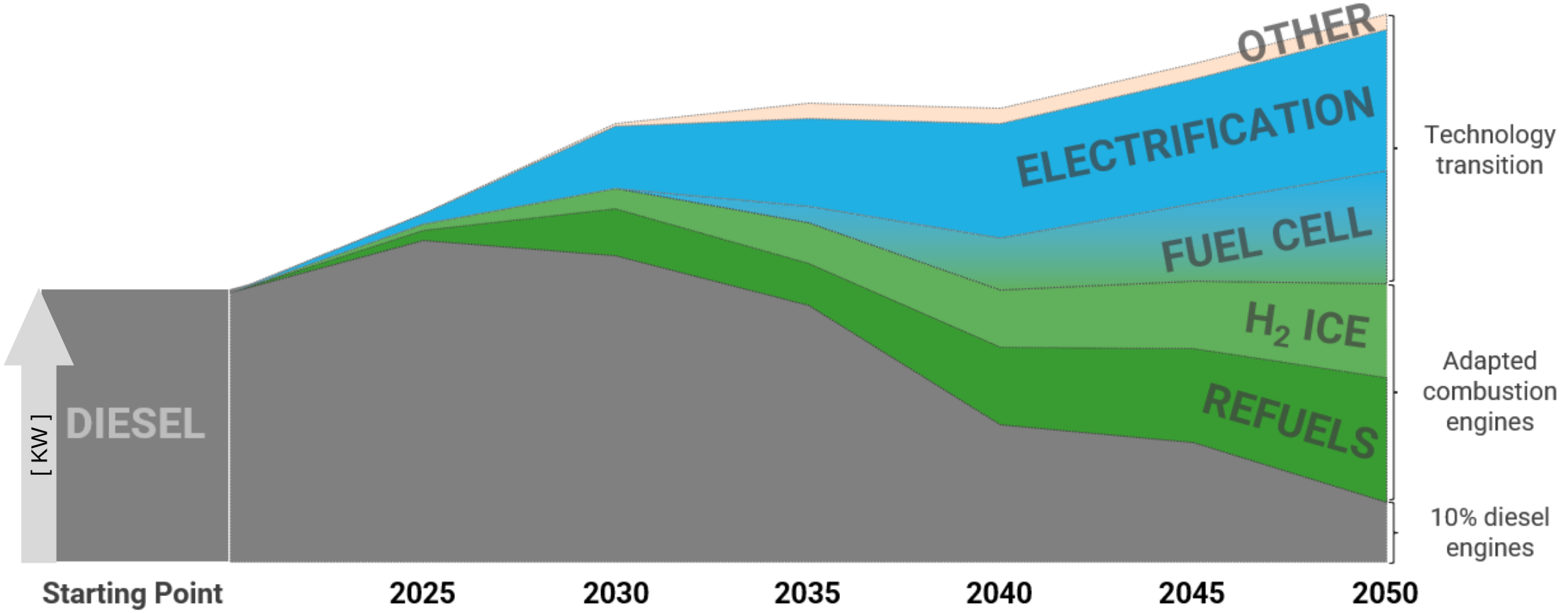
Modular battery systems

Fuel cell

Green electricity

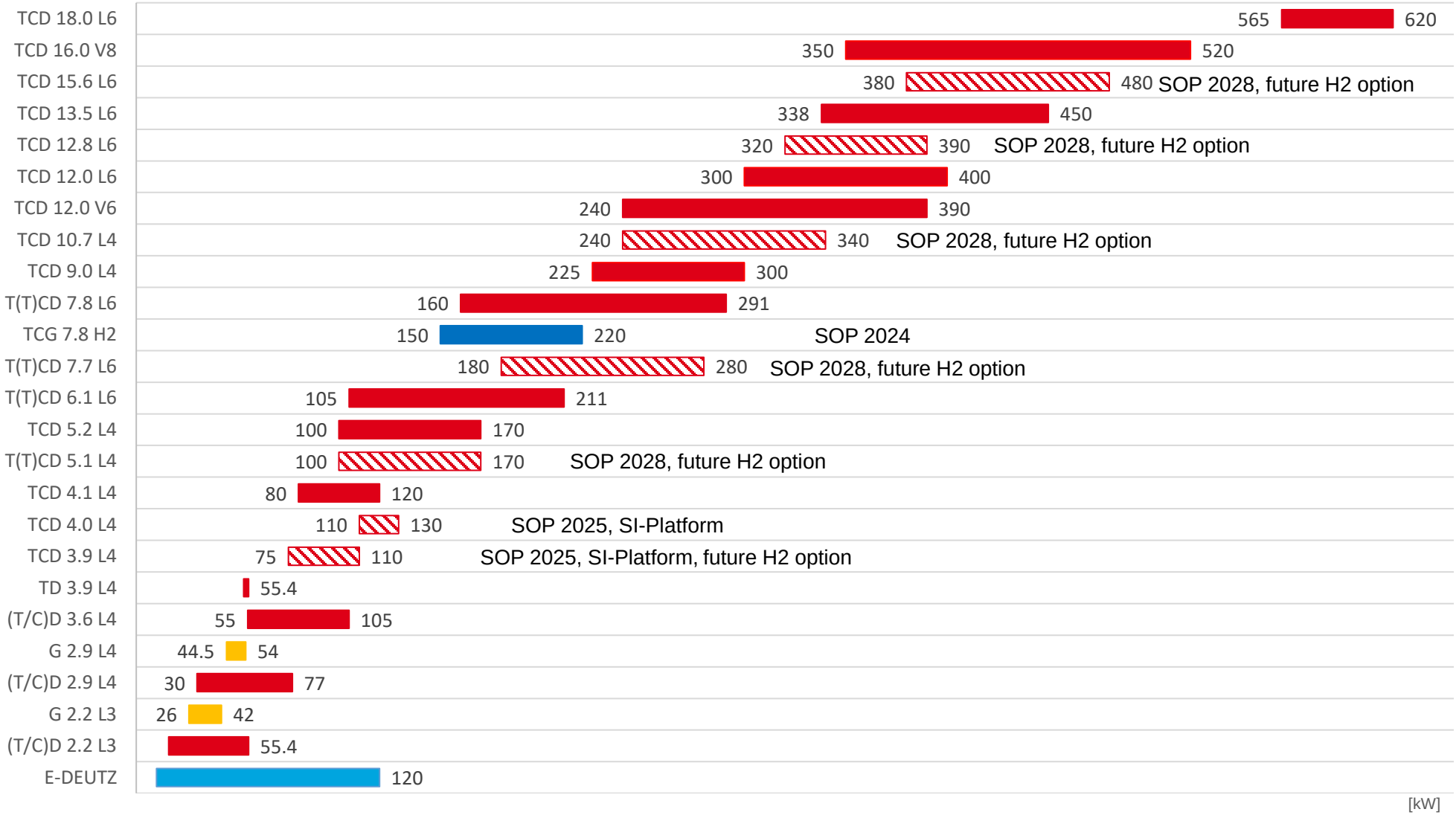
Sustainable Drive Portfolio for the CO_2-free Construction Site

Technology Allocation of DEUTZ Engines Until 2050



DEUTZ Engine Portfolio

Scenario **2028+**: Engines for high & low regulated markets



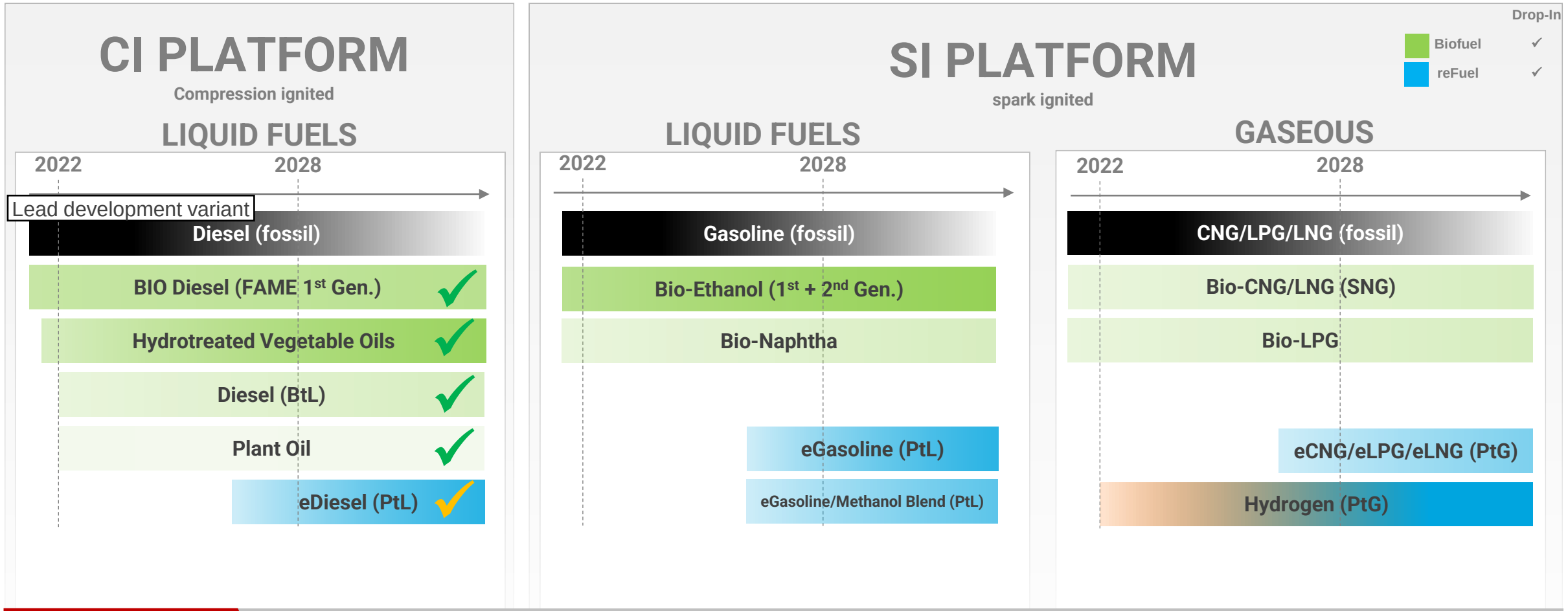
Diesel
New engines/projects
CNG / LPG / Gasoline
Hydrogen
Electric

TCD → Diesel direct injection
→ Charge air cooled
→ Turbocharged
5.2 → Displacement [l]

L6 → Inline 6 cylinder
V6 → V - Engine

Future fuels: Diesel / Renewables / GAS / Gasoline / H2

DEUTZ Expert Assessment



Key Message

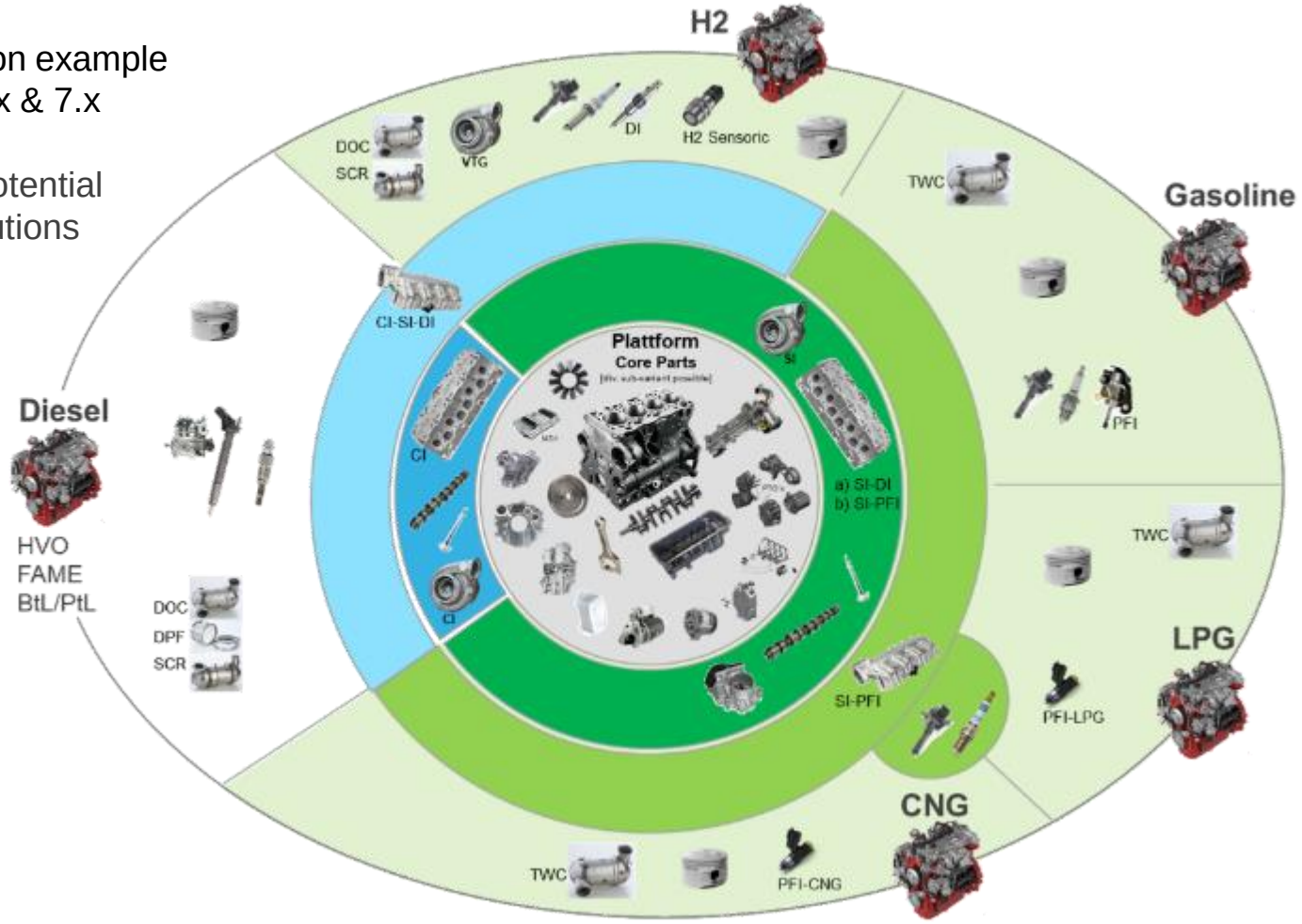
- DEUTZ Modular CI-SI engine platform to prepare for future fuel mix
- Tier 5 technology to be detailed

Future fuels: Diesel / Renewables / H2 / GAS / Gasoline

Vision: Modular CI-SI Engine Platform for T5/Stage VI Evo

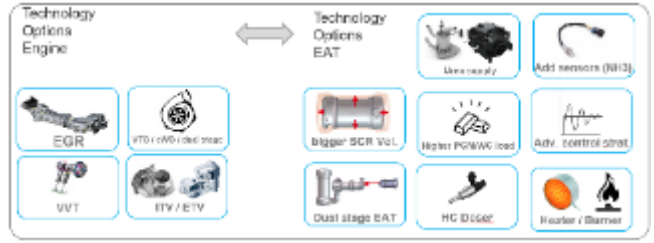
Visualization example
for EVO 5.x & 7.x

Optional potential
Hybrid solutions

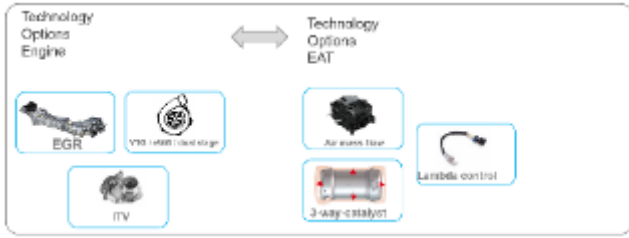


Vision: EAT System T5/Stage VI

EAT for CI-Platform



EAT for SI-Platform



EDG solution for CI-SI Platform
➔ Engine without EAT

Key Message

- **Modular CI-SI Platform recommended for future readiness (variant consolidation)**
- **Platform concept as enabler for future volume concentration at suppler**
- **EAT for SI less complex than for CI**

Future Fuels: What is driving clean fuel development?

Vision: availability of alternative clean fuels: H2, Electric, etc.

Federal Policy laws Enacted:

- Infrastructure Investment & Jobs ACT (IIJA)
  - $7 billion available for Hydrogen Hubs
  - $1 billion available for Hydrogen Production Research

- Inflation Reduction Act (IRA) •
  - $3/kg Production Tax Credit for Clean H2 (green), $40K/truck
  - Improved economics of hydrogen as a fuel across the economy

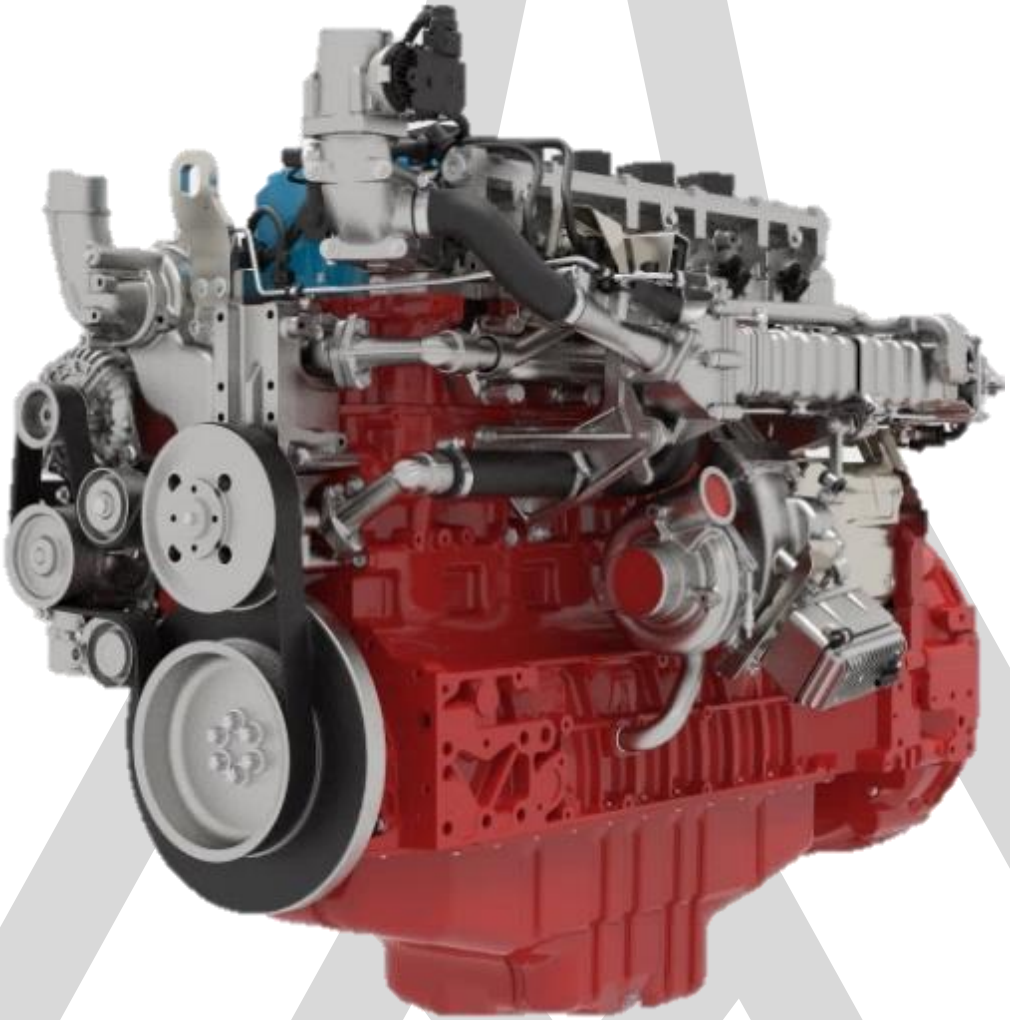
State Policy laws Enacted:

- ACF Advanced Clean Fleet Rule (California)
- Tax Credits, Vehicle & Infrastructure Incentive Programs

Key Message

- **Programs at the Federal Level Drive Innovation for Fuel Supplies (IRA, IIJA)**
- **Programs and Mandates at the State Level Influence H2 Technology and Supply**

DEUTZ (H2) Hydrogen Engine



DEUTZ TCG 7.8 H_2

Advantages of a Hydrogen engine

DEUTZ TCG 7.8 H2

- CO_2-free Combustion: $2H_2 + O_2 \rightarrow 2H_2O$*
- Economic alternative to other technologies
  - Attractive overall cost perspective
    (Initial invest is lower than with Fuel Cell drive)
  - Retrofit existing fleets possible (same drive train, additional H2-supply/tank plus safety)
- Could be industrialized in a short time with proven supplier infrastructure and existing production capacities
- Suitable for low H_2-gas qualities (lower costs, less processing than with fuel cells)
- High reliability grounded on proven base engine tech.
- Increasing H_2-infrastructure, available Maintenance-network for combustion engine

**) < 1 g CO_2/kWh*
** Idealized*

DEUTZ TCG 7.8 H_2 Hydrogen Internal Combustion Engine

An engine with a wide range of applications

Off-Road applications

- Excavators
- Tractors & agricultural machinery
- Mining

- Generators *(GenSets)*
- Block heat and power plants

Rail applications

- Regional trains
- Special vehicles

City and intercity buses*

- Medium range buses, 12m
- Complement to BEV city centre fleets

Delivery trucks*

- 16-18t trucks
- delivery traffic

Marine applications**

* On development request
** Possible future development

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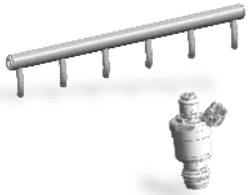
Conversion from Diesel- to Hydrogen engine

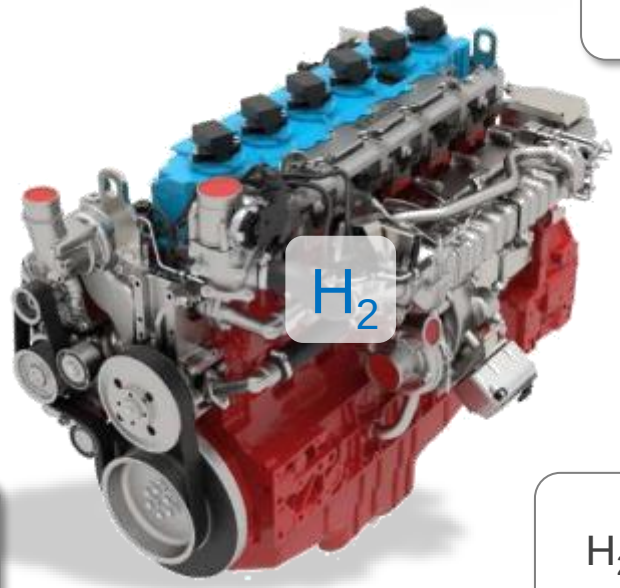
Improved Gas exchange valves and seats

Improved Piston

Turbocharger-Matching



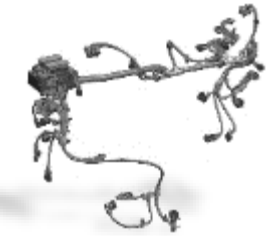
H_2-Injectors (PFI)

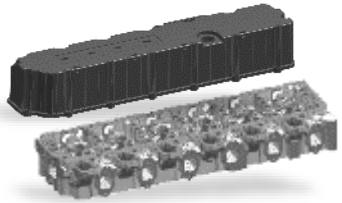


Exhaust-Gas-Recirculation (EGR)

Ignition System for Lean Combustion

Sensors and actuators





Cylinder head (Integration of ignition system)

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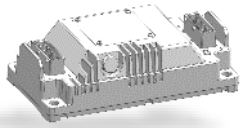
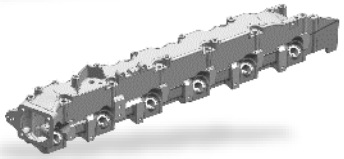
H_2-ECU and H_2-Software





Inlet Port (integration of H_2-injectors)

SCR-System *

* *As needed*

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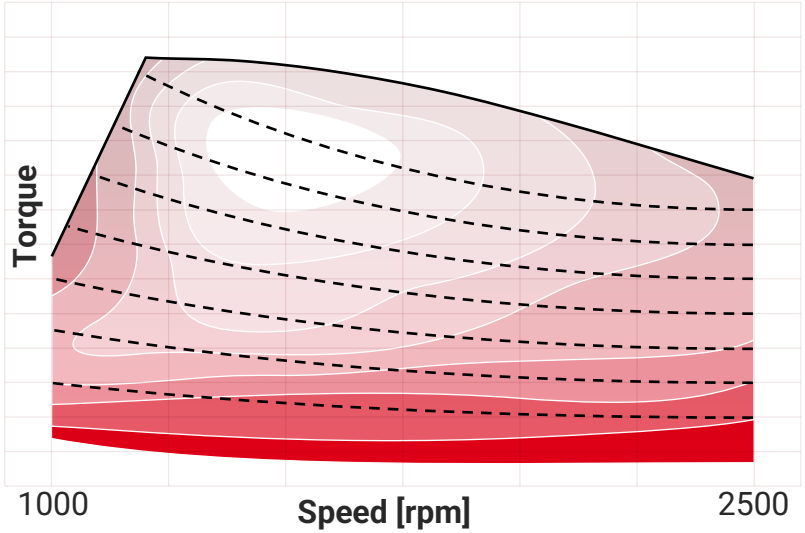
Applications



Specification	
Cylinder	6 in-line
Displacement	7,755l
Bore / stroke	110 / 136mm
Max. power	220 kW @ 2200rpm
Max. torque	1000 Nm @ 1000 – 1600rpm
Certification	Planned EU Stage V, EU Zero Emission[1]
Exhaust aftertreatment	SCR[2]

1. <1 g CO_2/kWh
2. necessary for high power density and dynamic

SERIES PRODUCTION IS PLANNED FOR 2024

Supportive Info for the Use Case Discussion

DEUTZ cooperation for H2 Tank System

- System up to 700bar operating pressure
  - Outlet pressure 30bar
- Refueling time down to 10 minutes
- Certification: R134, HGV-2, ADR
- Tanks are Type IV liners (2140mmx560mm / 185 kg) made of carbon fiber composites

DEUTZ partners with experts capable to support in these projects

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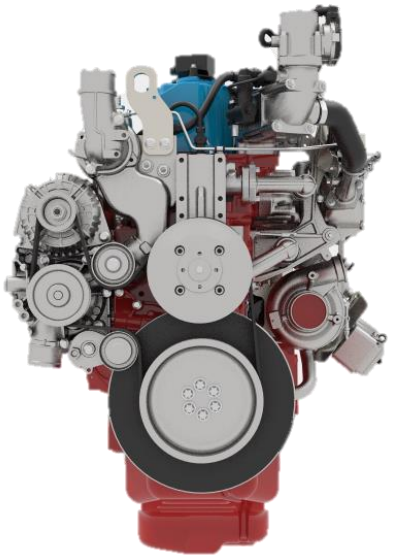
Sneak preview on key facts

Target Engine Specification for development:

- Cylinder 6 inline
- Displacement 7.8 L
- Bore / Hub 110 / 136 mm
- Max. Power 220 kW @ 2200 rpm
- Max. Torque 1000 Nm @ 1400 - 1600 rpm
- H2 consumption: up to ~19 kg/h @max. power
- Hydrogen quality: ISO 14687 min. 98% or higher
- Pressure interface: 30 bar
- Useful Life: 10,000 hr
- Certification*: Stage V, US SI Tier 2
- Exh. After-Treatment*: Possible OC** and SCR
- Emission Target: CO2 <1g/kWh



*certification process not finalized. OC may be needed for safety reasons
** Oxidation Catalyst

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H2 Re-fueling / Infrastructure

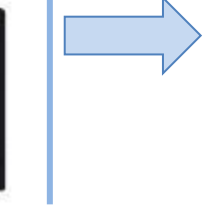
Task:

- Assessment of H2 re-fueling infrastructure
  - At construction site vehicles and agricultural machinery

Challenge:

- The LHV of diesel is 45.6 MJ/kg whereas H2 is ~120MJ/kg,
- However,
  - Hydrogen gas is typically 5.7% of the total mass of fuel storage system: Leading to an overall H2 energy density of 6.8 MJ/kg
  - Construction and agricultural machinery limited mobility (work performance due to mass)

➔ Provision of hydrogen re-fueling directly on site

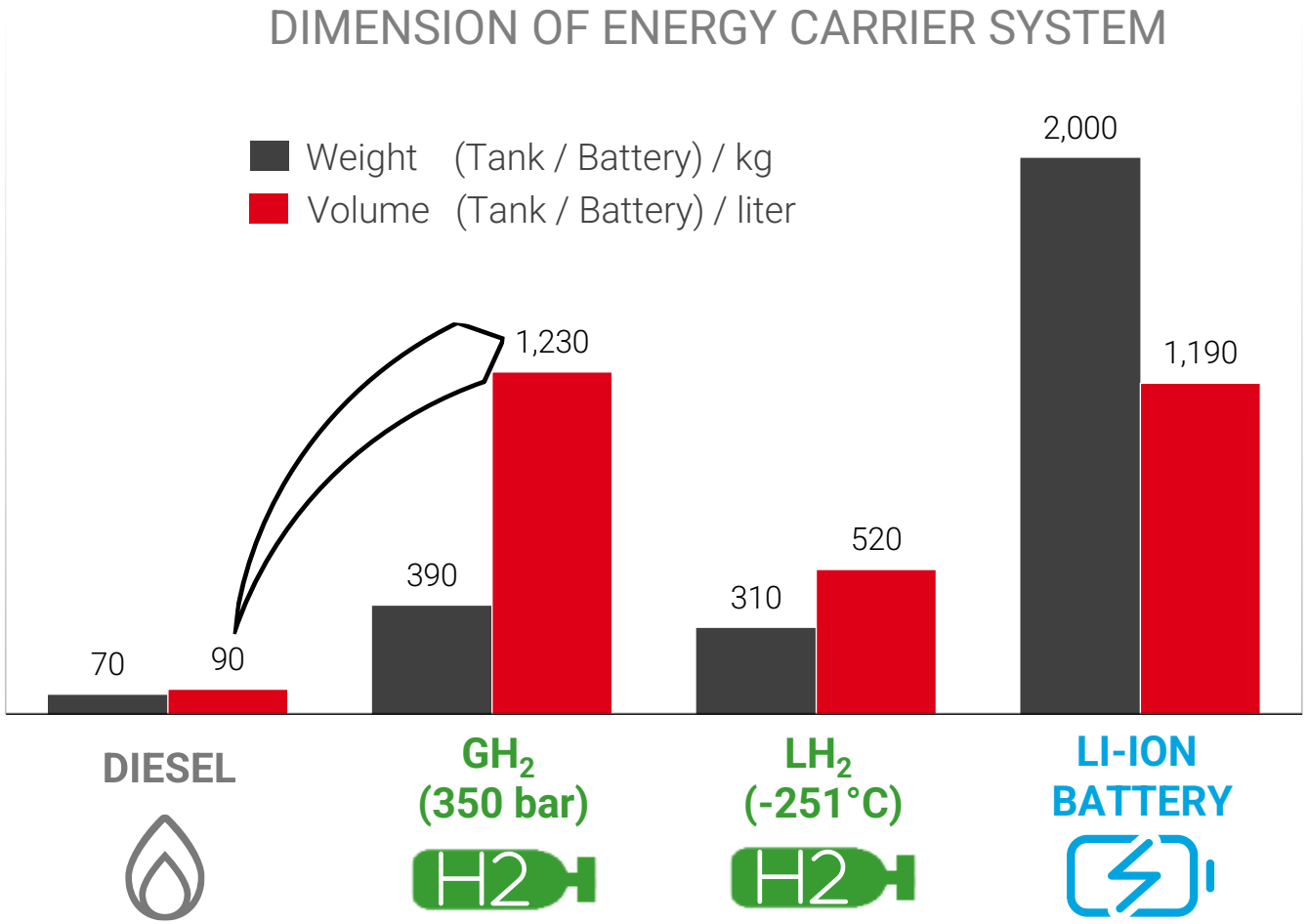


Solutions for CO_2-free Powertrains

Case Study: Gravimetric and Volumetric Comparison of Energy Carriers

Nominal Engine Power:	200 kW
Average Engine Load:	60 kW / 30%
Operation time per day*:	2x4h
Efficiency Diesel / H2	38%
Efficiency BEV (Li-Ion)	75%

**one refuelling / recharging cycle during lunch break*



TANK MASS AND VOLUME ARE A CHALLENGE

TCG 7.8 H2 – Emission Performance

Preliminary Results from Standard Test Cycles

- C1 and RMC data taken post SCR (tailpipe out), no DPF

			NO	NO2	NOx	HC	CO	PM	CO2	O2	PN
			g/kW-hr								
Power Category (130 - 560kW)	Test Cycle	C1	0.012	0.005	0.017	0	0	0.001	5.0	--	--
		RMC	0.011	0.009	0.020	0	0	0.001	4.9	581	2.22E+09
	US EPA limits (1039, 1048)	Tier 4 - CI	--	--	0.40	0.19	3.5	0.02	--	--	--
		Tier 2 - Large SI	--	--	0.8		20.6	--	--	--	--
	EU ST V Limits	CI	--	--	0.4	0.19	3.5	0.015	--	--	1.00E+12
		SI	--	--	0.4	0.19	3.5	0.015	--	--	1.00E+12

- Ambient air is 0.04% (~421ppm) CO2 which is measured at tailpipe out
- CO2 contribution from DEF (Diesel Exhaust Fluid): $H_2N\text{-}CO\text{-}NH_2 \rightarrow CO_2$

*Emission data presented are preliminary, not part of a certification

Key Message

- **All regulated emissions are within current US and EU**
- **H2 is considered CO2-free since the fuel does not contain Carbon**

TCG 7.8 H2 – Emission performance

Comparison with underground mine ventilation requirements

- C1 data

		kW @ RPM	After-treatment	NOx	HC	CO	PM	CO2	Ventilation (cfm)
				g/kW-hr					
CI - Tier 3	**TCD 2013 L06**	190 @ 2300	No	3.8	0.12	0.41	0.097	756	10,700
CI - Tier 4	**TCD 6.1 L6**	180 @ 2300	Post	0.08	0.012	0.01	0.012	773	11,000
SI	**TCD 7.8 H2***	220 @ 2200	Pre	0.51	0	0.023	--	4.3	500
			Post	0.02	0	0	0.001	4.9	500

*Emission data presented are preliminary, not part of a certification or approval

Key Message

- **Hydrogen ICE present opportunity to reduced ventilation rates**

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Emission Data Analysis

Zero Emissions vs. Zero Carbon Emission

- H2 ICE can be more efficient than diesel with near zero or zero-carbon emission acceptance
  - Still some carbon emissions from lubricating oil and DEF
  - Emissions of NOx from high temp/press combustion. Emissions control could be needed
- Smaller aftertreatment system footprint compared to Diesel

Take-away thoughts

- Fuels Sourcing – Improvements to be made within the fueling infrastructure
- Gas vs. Liquid H2 On-site storage
- Safety and Training – managing high pressure or low-temp storage

Thank you!

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